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NITRATE AND CHLOROPHYLL DISTRIBUTIONS IN RELATION TO THERMOHALINE STRUCTURE IN THE WESTERN TROPICAL PACIFIC DURING 1985-89

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INTRODUCTION

During the TOGA period, the western Pacific received great attention because it is considered as a key region for the understanding of the ENSO early stages. The ensuing studies contributed to a better description of the physical structure of the surface layer and of annual and interannual variability of the environmental variables. This was an opportunity for biologists to complement the poorly documented nitrate and Chl *a* distributions and their temporal variability in the western Pacific. Our purpose is to contribute to answer the question: are the physical parameters variations, observed on a seasonal or interannual time scale, reflected on nitrate and Chl *a* distributions? The 165°E meridian, where different situations are encountered and low frequency (intraseasonal, seasonal, and interannual) variability is evidenced, appears as an interesting site for such a study.

DATA

Sixteen cruises (Figure 1) were carried out along 165°E from 20°S to 10°N during the 1985-89 period by ORSTOM Nouméa. The Southern Oscillation Index (SOI) during 1985-89 shows three periods: 1985-86 defined as "reference", the moderate 1986-87 El Niño, and the strong 1988-89 La Niña. CTD probes were used to measure temperature and salinity. Nitrate and Chl *a* samples were collected using a 12-bottle-rosette system. Different data processing and methods are detailed in Delcroix et al. (1992) and Radenac and Rodier (submitted). Note that the Chl *a* concentration resulted from two different methods: before and after July 1987.

The top of the thermocline and the mixed layer depths were discriminated using vertical gradients criteria (0.05°C m^{-1} and 0.01 kg m^{-1} respectively) as described in Lukas and Lindstrom (1991). The nitracline depth, representing the deepest limit of the layer where nitrate is assumed to be limiting, is the first depth where $NO_3 > 0.1$ µM.

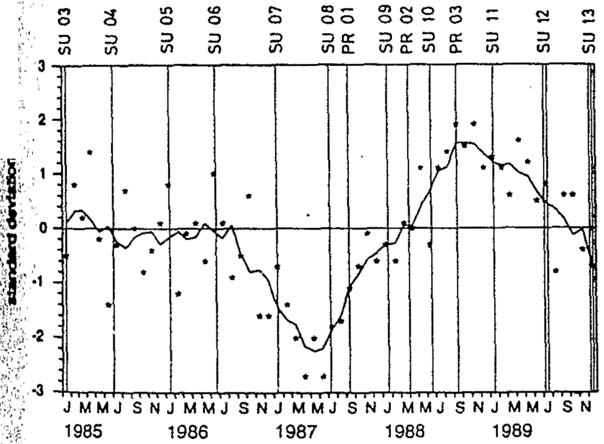

Figure 1- SOI in 1985-89 (Courtesy of the CAC, Washington, D.C., USA). Vertical lines denote cruises (SU for SURTROPAC, PR for PROPPAC).

TYPICAL OBSERVED FEATURES

Four different situations are described in this note by means of density, nitrate, and Chl *a* distributions along 165°E (Figure 2); thermohaline and current structures are detailed in Delcroix et al. (same issue). The various conditions encountered from the south to the north of the transect are shown in the "reference" section. The three following sections emphasize the great variability in the equatorial zone.

Reference: 10-26 January 1985 (SURTROPAC 05). The surface layer was nitrate depleted ($NO_3 < 0.1$ µM) and its Chl *a* content was low. The pycnocline and nitracline were deep except at 10°S

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where a ridging of the different properties was observed. At the equator, this situation contrasts with the commonly described upwelling in the other parts of the equatorial Pacific. The depth of the deep Chl a maximum (DCM) matched the depth of the nitracline. Subsurface nitrate concentration was low south of 10°S and high north of 5°N.

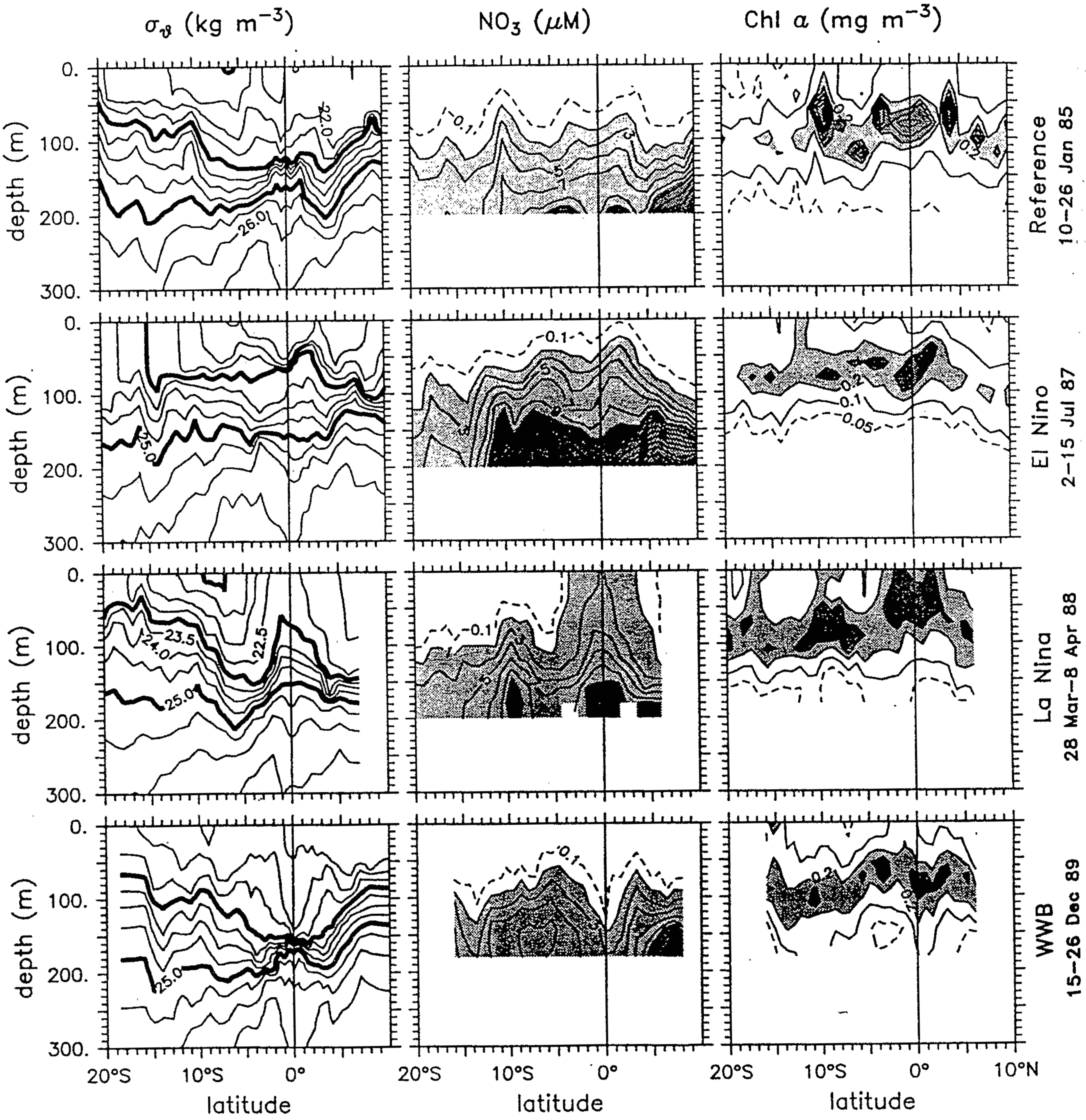

Figure 2- Meridional sections of σ_θ, nitrate, and Chl a distributions along 165°E. From top to bottom: Jan. 1986 (reference); Jul. 1987 (El Niño); Mar.-Apr. 1988 (La Niña); Dec. 1989 (westerly wind burst).

El Niño: 2-15 July 1987 (SURTROPAC 08). In the 5°S-5°N zone, a shoaling of the different properties was observed: shallower and sharper pycnocline and nitracline, rising of the nitrate reservoir. The surface nitrate concentration remained undetectable and surface Chl a was very low.

La Niña: 28 March-8 April 1988 (PROPPAC 02). In the equatorial zone, the distributions of the properties were remarkably different from the preceding transects owing to the development of an upwelling. The highest nitrate and Chl *a* surface concentrations of the period were observed. The mixed layer was deep and the Chl *a* maximum, much smoother than during the previous cruises, was situated around 60 m.

Westerly wind burst (WWB): 15-26 December 1989 (SURTROPAC 13). In a narrow equatorial band, besides strong modifications of the thermohaline and current structures (McPhaden et al., 1992), effects of WWB on nutrient vertical distributions were intense. About 10 days after the beginning of the wind event, the deepening of the nitracline was concomitant with the density structure adjustment (nitracline and pycnocline at 140 m). Interestingly, at the considered time scale, no striking deepening of the Chl *a* distribution occurred (Chl *a* maximum about 50 m above the nitracline).

VARIABILITY

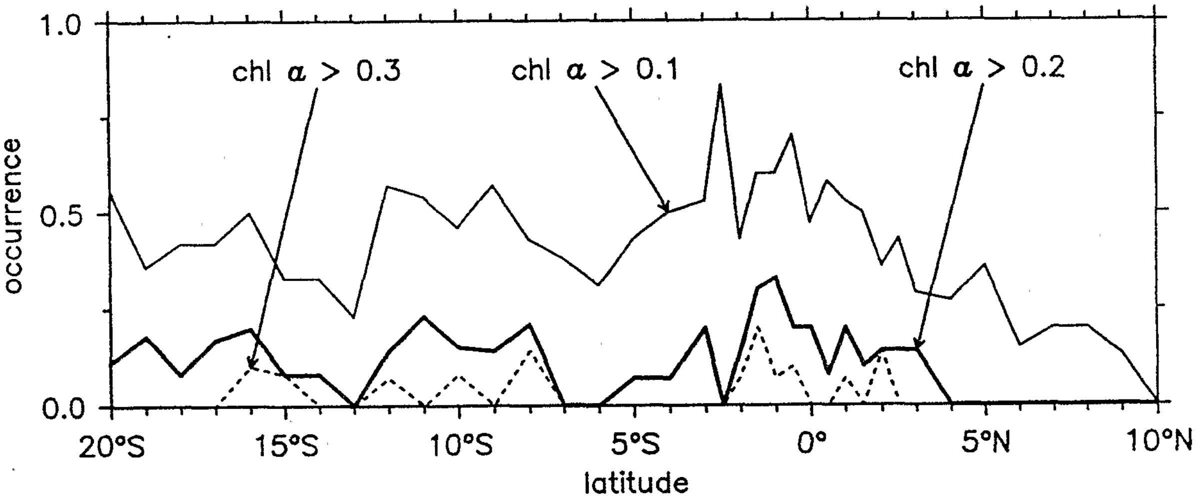

Figure 3- Occurrence of Chl *a* at the surface along 165°E. Note the sequence of cruises during the 1985-89 period: 4 during the reference period, 2 during El Niño, 6 during La Niña, 7 during Dec.-Jan.-Feb., 6 during Jun.-Jul.-Aug.

Occurrence of Chl *a* at the surface (Figure 3) is an index of variability during a definite period as surface Chl *a* concentration and its variations partly reflect the vertical thermohaline and nitrate distributions and their modifications. North of 5°N, because of the strong density stratification, the occurrence was very low; in the 5°S-5°N region, the high occurrence reflected the presence of the upwelling (high number of cruises during La Niña); at 10°S, frequent transient events explained the high occurrence; south of 15°S, variability was essentially seasonal (50% of occurrence). Figure 4 shows time-series of characteristic depths in these regions.

The 6°N-10°N region. Despite the highest subsurface nitrate concentration of the transect, the surface Chl *a* is always very low (≤ 0.1 mg m^{-3}) because of a strong $\partial\rho/\partial z$ (≈ 0.10 kg m^{-4}) in the 50-100 m layer which prevents upward nitrate flux and traps the DCM. The seasonal and interannual variations of the mixed layer depth were not echoed on the nitracline and DCM the depths of which were strongly dependent on the maximum density gradient variations. Their seasonal and interannual variations were partly influenced by the local wind forcing through the Ekman pumping mechanism (not shown).

The 2°S-2°N region and its limits. Interannual, seasonal, and intra-seasonal variations of the nitrate and Chl *a* distributions were observed.

The reference period. The surface layer was nitrate depleted and the surface Chl *a* concentration (0.10-0.20 mg m^{-3}: Barber and Kogelschatz, 1990) was low. The DCM lays above 100 m in a layer where the density stratification was weak and its seasonal variations strongly influenced by salinity. The DCM depth followed the same control.

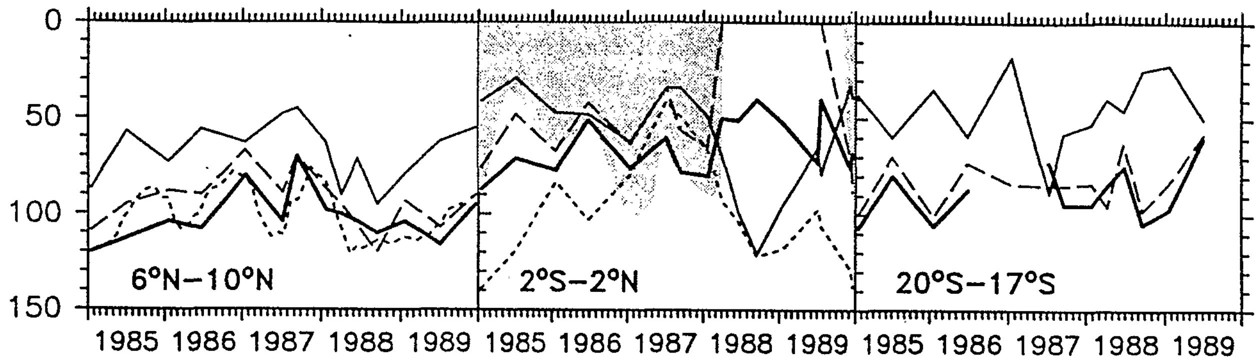

Figure 4- Time-series of characteristic depths averaged in three latitude ranges. From left to right: the 6°N-10°N region; the 2°S-2°N region (salinity lower than 35 psu is shaded); the 20°S-17°S region. Solid line: mixed layer depth; long dashed line: nitracline depth; heavy line: DCM depth; short dashed line: depth of the 25°C isotherm (6°N-10°N) or depth of the top of the thermocline (2°S-2°N).

The El Niño period. Despite the rising of the nitrate reservoir and because of a stronger and shallower maximum $\partial\rho/\partial z$ (both being the consequences of the basin-wide tilt of the thermocline), surface nitrate remained lower than 0.1 µM and Chl *a* was abnormally low (< 0.10 mg m^{-3}). Significant intra-El Niño variations of the DCM and nitracline depths (in the same range as during the reference years) were caused by variations of the fresh water layer depth.

The La Niña period. This period was characterized by an equatorial upwelling associated with a very weak stratification from the surface to more than 100 m, significant nitrate (up to 3.2 µM) and Chl *a* (> 0.20 mg m^{-3}) concentrations at the surface, and a remarkably constant DCM depth (40-60 m). In contrast with the central Pacific, the upwelling is limited by oceanic convergences at the northern and southern edges of the South Equatorial Current. Its seasonal meridional displacements (particularly well evidenced with surface nitrate: Figure 5) toward the winter hemisphere followed the alternation of northeast and southeast equatorial trades. This was confirmed in terms of meridional Ekman transport. Variations of surface nitrate and Chl *a* concentrations (not shown) were strongly associated with local zonal wind stress variations. It is highly probable that remote forcing affects the Chl *a* distribution as a modification of the mixed layer depth and of the nutrients vertical structure is associated with equatorial waves.

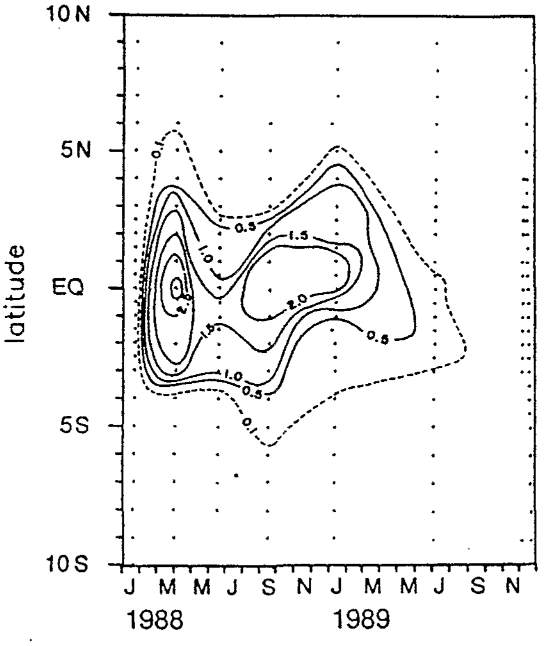

Figure 5- Sea surface NO_3 concentration during La Niña. NO_3 > 0.1 µM is shaded, NO_3 > 2 µM is dark shaded, contour interval is 0.5 µM.

The 10°S region. The influence of the divergence at the southern edge of the South Equatorial Counter Current on the vertical displacements of water (Merle et al., 1969) and the Ekman pumping always favorable to upwelling (Delcroix and Hénin, 1989) are two possible explanations of the often reported ridging. More easily than in the surrounding latitudes, a local wind event can result in turbulent entrainment at the base of the mixed layer, allowing nutrients into the surface layer and transient surface enrichment in nitrate or

Chl *a*. If this analysis is rational, higher probability of surface enrichment is expected in the middle of the year or during El Niño periods, as both the wind stress and its curl are stronger.

The 20°S-17°S region. Seasonal variability is evidenced for the DCM depth (110 m in summer, 80 m in winter) and the sea surface Chl *a* concentration (0.075 mg m^{-3} in summer, 0.150 mg m^{-3} in winter). In summer, the DCM is deeper because the amount of light is greater than in winter and the vertical mixing, limited to a superficial layer, has no influence on the nutrient input toward the surface. In contrast, the deeper winter vertical mixing may be responsible for nutrient supply toward the lighted layer and for erosion of the DCM and was associated with higher Chl *a* content at the surface.

CONCLUSION

The vertical Chl *a* structure is mainly the result of the availability of light and nitrate, and is strongly related to the vertical stability of the water column that governs the displacements of phytoplankton in the light and nitrate gradients. Therefore, local or remote physical processes that govern the low-frequency (interannual, seasonal, intra-seasonal) variability of the thermohaline structure play a dominant role in the control of low-frequency variability of nitrate and Chl *a* distributions.

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